HOW GEOECOLOGICAL COMPONENTS OF A TERROIR CAN BE ALTERED BY SPATIAL CHANGES OF VINEYARDS – A CASE STUDY FROM EGER WINE DISTRICT (HUNGARY)

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With 10 figures and 2 tables
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Summary: Terroir is a concept referring interactions of natural (topography, lithology, climate, soil etc.) and human (economic conditions, traditions, cultivation practices, etc.) factors; therefore, terroir is spatially delimited and subjected to environmental, socio-economic, and temporal changes. The geoecological background of wine districts are considered more stable among them, but, because of its natural diversity and the spatial changes of production sites, changes in abiotic terroir components might occur too. In this study the spatial changes of grape production sites in Eger Wine District (Hungary) across two and a half centuries (1784 to 2018), and their consequences on the composition of the geoecological factors (lithology, topography, soil characteristics) were analyzed. Modernization of cultivation, urbanization and increase of built-up areas around the central settlement resulted in decreased concentration, i.e. increased spatial dispersion to more remote vineyards further from Eger. It also has consequences on the lithological and topographical composition of the production sites. Besides the slightly increasing extent of vineyards (from 5346 ha to 7413 ha) we found a distinct decrease of vineyards at higher elevations and a substantial increase at lower elevations. Distribution according to slope gradient changed also remarkably, with the share of vineyards on <5% slopes from 38% to 65%. These changes resulted in transformations of pedological characteristics according to the comparison of vineyard's extent with soil map data: vineyards shifted to slightly acidic, more fertile (i.e. deeper soil layer with higher organic carbon content) soils. The share of vineyards with different lithology and parent material also changed: loose, calcareous Tertiary sediments decreased almost to half, and the share of vineyards over acidic volcanics and their weathered regoliths almost doubled. Comparing these two dominant lithological types and soil profiles derived from them, different pedological characters and taxonomic status were found (Phaeozems and Vertisols). However, comparison of these two lithological types based on main topsoil characteristics (pH, SOC, carbonates, depth of fertile soil layer, N, P, K content) according to 25 randomly chosen surficial soil samples at production sites, showed no significant differences.. In the case of this particular wine district, spatial changes of the production sites affected mostly the distribution by elevation, by slope gradient, but did not alter significantly the surface soil character of the terroir.

Zusammenfassung: Der Begriff Terroir steht im Weinbau für den originären Charakter eines Weinbauareals durch das Wirkungsgefüge naturräumlicher (Topografie, Lithologie, Klima, Boden usw.) und menschlichen (wirtschaftliche Bedingungen, Traditionen, Anbaupraktiken usw.) Faktoren. Das Terroir ist räumlich begrenzt, unterliegt aber ökologischen, sozioökonomischen und zeitlichen Veränderungen. Zwar gilt der geoökologische Hintergrund der Weinbaugebiete als relativ stabil, aber aufgrund der natürlichen Vielfalt und der räumlichen Veränderungen der Produktionsstandorte können auch Verschiebungen der abiotischen Terroirkomponenten auftreten. In dieser Studie wurden die räumlichen Veränderungen der Weinbauflächen im Weinbaugebiet Eger (Ungarn) über zweieinhalb Jahrhunderte (1784 bis 2018) und ihre Auswirkungen auf die Zusammensetzung der geoökologischen Faktoren (Lithologie, Topografie, Bodeneigenschaften) analysiert. Die Modernisierung des Anbaus, die Verstädterung und die Zunahme der bebauten Areale im zentralen Siedlungsbereich führten zu einer stärkeren räumlichen Streuung auf weiter entfernte Weinberge in der Nähe von Eger. Der Anteil der Weinberge mit unterschiedlicher Lithologie und unterschiedlichem Ausgangsmaterial hat sich dadurch verändert: lockere, kalkhaltige tertiäre Sedimente gingen fast auf die Hälfte zurück, und der Anteil der Weinberge über saurem Vulkangestein und dessen verwitterten Regolithen hat sich fast verdoppelt. Beim Vergleich dieser beiden vorherrschenden lithologischen Typen wurden unterschiedliche bodenkundliche Merkmale und ein unterschiedlicher taxonomischer Status festgestellt (Phäozeme und Vertisole). Ein Vergleich dieser beiden lithologischen Typen anhand der wichtigsten Oberbodenmerkmale (pH, SOC, Karbonate, Tiefe der fruchtbaren Bodenschicht, N-, P- und K-Gehalt) anhand von 25 zufällig ausgewählten oberflächlichen Bodenproben ergab allerdings keine signifikanten Unterschiede. Im Fall der untersuchten Weinbauregion wirkten sich räumliche Veränderungen der Produktionsstandorte vor allem auf die Verteilung nach Höhenlage und Hangneigung aus, veränderten aber nicht wesentlich den Charakter des Oberbodens.

Keywords: Vineyard soils, land use change, components of terroir, alteration of terroir, phaeozem, vertisol, agricultural geography, GIS, Central Europe

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1 Introduction

The geoecological character of vineyards includes geology, soils (chemical and physical characteristics), topography (elevation, exposition), and microclimatic conditions (Agnoletti et al. 2015). Among many other biotic, economic, social and cultural factors (like grape varieties, traditions, wine making technologies, etc.) the geoecological character contributes substantially to the character of wines and wine districts, called, popularly, 'terroir' (Van Leeuwen & Seguin 2006, Vaudour et al. 2015) (Fig. 1). Considering the geodiversity of the production sites, the location of the vineyards may not be translocated significantly within a wine district without significant changes in the geoecological character of the production sites. Detailed mapping and zoning of terroir based on field and remotely sensed data therefore become increasingly important (Bonfante et al. 2011, Priori et al. 2019, Bramely et al. 2020, Czigány et al. 2018, Czigány et al. 2020). Abiotic components of the terroir, like the bedrock of soils, soil type, nutrient status of soils, slope aspect, slope gradient, etc. may show significantly altered composition after spatial translocations of grape production (Arnó et al. 2012, Constantini et al. 2016). Climate change affecting the terroir has also been discussed in numerous studies (Jones 2006, Bernetti et al. 2012, Fraga et al. 2016, Bonfante et al. 2018).

In our study we analyzed how the spatial reorganization of plantations can affect the abiotic components of a terroir. The more diverse the geoecological background of a wine district is, the higher the risk of changing the wine's character will be after spatial reorganization of the production sites (Fig. 1).

This is worth keeping in mind that technological and socio-economic changes during the past two centuries have significantly reshaped the spatial pattern of cultivated vineyards within traditional wine producing areas in Europe (Serra et al. 2008, Gerard et al. 2010, Varga et al. 2013, Munteanu et al. 2014, Carbone 2019). The phylloxera disaster devastated extensive plantations (Stevenson 1980), and the reconstructions after it were carried out based on altered preferences (Boros 2008, 2011, Nyizsalovszki & Fórián 2007). The newly introduced grape sorts required new technologies and demanded different growing sites. Machinery cultivation and industrialization in production, coupled with altered wine consumption habits and other socio-economic conditions (Bicik et al. 2001, Bürgi et al. 2004) led to reorganization of the plantations in most of the wine regions (Constatntini et al. 2016, González et al. 2017, Dobos et al. 2014). The plantations shifted mostly to downslopes, and into the direction of sites, which are easier to cultivate and still produce satisfying quality, as well as larger amounts of vine (Dobos et al. 2014, Jordan et al. 2005, Kiss et al. 2005, Novák & Incze 2014, Novák et al. 2014, Renwick et al. 2013). Studies from many European vine regions report about relocation of vine production to less steep slopes, with deeper soils, having less skeletal parts in the topsoil horizons and higher organic content (Borelli et al. 2017, Iglesieas et al. 2012, Lieskovsky et al. 2013).

Those changes, of altered preferences in selection of production sites within a geographically diverse environment, affect not only the quality and quantity of wine production (Arnó et al. 2012), but might also have led to the changes in the characteristic geoecological components of the terroir (Vaudour 2002, Basso 2019, Kuemmerle et al. 2008, 2013, Baumann et al. 2011). Finally, the spatial reorganization of vineyards within a particular wine district might alter the character of the local wines (Fig. 1).

Our assumption was that progress of the industrialized and mechanized management of production within the studied wine district during the past 234 years has changed the extent, and spatial distribution of vineyards, and, consequently, affected the distribution of characteristic values of geological and geographical factors among the vineyards, too. The main questions of this study are:

- How has the spatial pattern of vineyards changed over time and what are the causes?
- How have spatial changes affected basic geoecological characteristics (topography, bedrock)?
- What influence did the changes have on typical soil characteristics (depth of soil layer, pH, soil organic carbon content, nutrients, soil type)?
- Did the spatial reorganization of vineyards significantly change the abiotic characteristics and thus of the terroir over the study period?

2 Study area

In Hungary there are 22 wine districts, belonging to 6 larger wine regions. The Eger Wine District, is one of the five wine districts within the Upper-Hungarian Wine Region, declared in the 102/2009 (VIII. 5.) and 127/2009 (IX. 29.) ministerial decrees of Ministry of Agriculture and Rural Development. The wine district embraces 20 municipalities and covers 591 km^2 within eight physical geographical microregions (Fig. 2), including foothills (Bükk

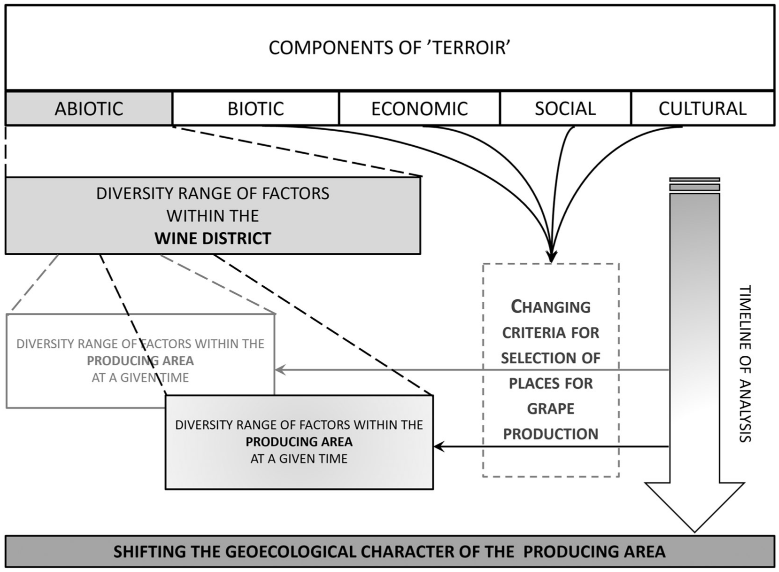


Fig. 1: Interactions among the components of a terroir and their changes along a chronosequential analysis

Foothills, 54.0%; Mátra Foothills, 4.2%), higher elevated hilly landscapes (Bükk 16.7%, Mátra 3.6%) alluvial valleys (Lower Tarna Valley, 5.0%) and adjacent lower floodplains as well (Hevesi Plain, 7.1%; Lower Tarna Plain, 5.9%; and Borsodi Mezőség, 3.6%) (Csorba 2020). Geoecological characteristics of vineyards like topography, parent material, soils and microclimate vary substantially among these microregions.

Geological diversity is remarkable. Miocene volcanics and Mesozoic sediments dominate the higher elevated landscapes, while Tertiary and Quaternary sediments cover the foothills and valleys (Gyalog 2005, Dövényi et al. 2010). The whole study area, delimited by the boundaries of municipalities belonging to the wine district, consists of Early Tertiary marine sediments, such as clay, marl, and limestones in 37.6%. Neogene volcanics and their weathering products cover 34.3%, Quaternary sediments, like alluvial, glacial deposits, aeolian loess and loess derivates occur on 13.6% of the area, and 14.4% is built up of Mesozoic limestones, dolomites, phyllites and shales in higher elevated mountainous landscapes (Fig. 2).

Elevation differences vary from 537 m, the highest in the Bükk Mountains, to 110 m, the lowest in the Lower Tarna Plain and Borsodi-Mezőség. As the main creeks and rivers (Tarna, Eger, Laskó) cross the area from north-west to south-east, ridges can also be characterized with the same orientation (Dobos 2012).

The climate of the wine region belongs to the warm temperate fully humid climate with warm summers (Kottek et al. 2006). Mean annual temperature within the vine district ranges between 8.2°C in the northern and 10.8 °C in the southern part (for 1961–2010). The coldest month is January (-2.0±0.5 °C), and the warmest July (20.4±0.8°C). The lowest amount of precipitation is in October (53.8±4.6 mm), and the highest in July (83.9±7.7 mm) on average for 1961–2010. The growing degree days of the vegetation period is 6.64±0.66 °C. The data above were calculated based on the FORESEE dataset (Dobor et al. 2014).

The potential natural vegetation of the area is oak forest, hornbeam-oak forest (Vojtkó 2001, Molnár et al. 2008) which has been strongly influenced by agricultural activities since the Neolithic age, vine production might have been present since the late Iron age by the Celtic population, but it became a characteristic part of the landscape during the Medieval Times.

The soils of the area are dominantly Cambisols and Luvisols (Świtoniak et al. 2014) under native forests. The presence of shrink-swell clay minerals in weathering products of volcanics might contribute to the vertic character of the soils or result in development of Vertisols in appropriate topographic positions (Stefanovits 1985). Due to erosion and colluviation processes, Cambisols and Leptosols are common in steep slope sections, and Regosols, i.e.

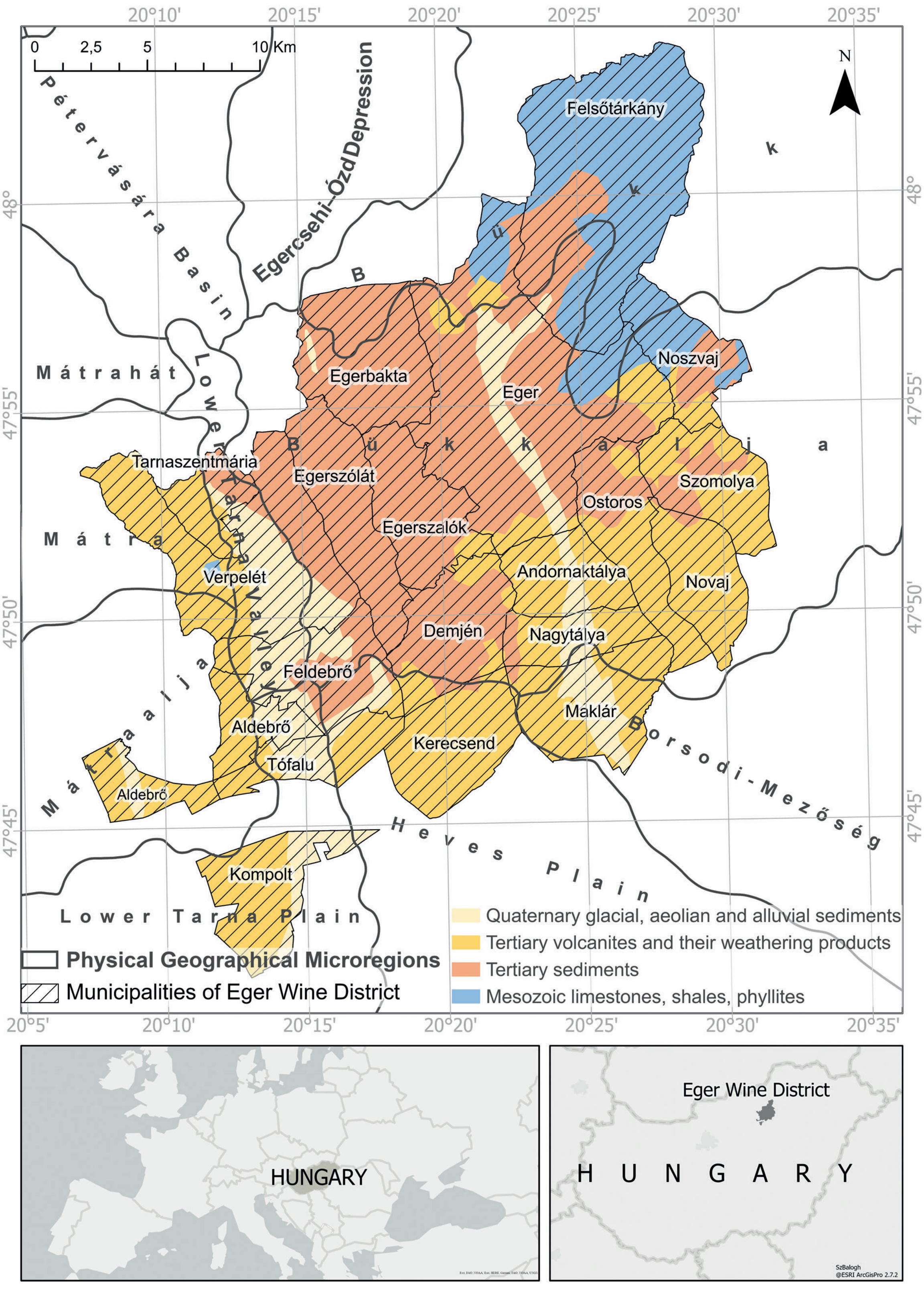


Fig. 2: Physical geographical microregions and municipalities within Eger Wine District

slope deposits with deep humus layer and weakly differentiated soil profile horizonation in toe slopes (Novák et al. 2018). The geochemical characteristics and carbonate status are highly depending on parent materials and range from acidic, unsaturated Umbrisols and Vertisols to the nutrient rich, calcareous Rendzic Phaeozems.

3 Materials and methods

3.1 Map data collection to study the spatial changes of vineyards

Historical maps allowed us to reconstruct long-term changes in spatial distribution of vineyards from 1784 to 2018 and delimit the extent of vineyards in eight consecutive datasets. The vineyards on historical maps, topographic maps, and in land cover databases and aerial surveys such as the First Military Survey Map (from 1784), the Second Military Survey Map (from 1858), the Third Military Survey Map (from 1883), topographic maps from 1941 and 1972, aerial photos from 2005, Survey Base Map from 2011 and Corine Land Cover database 2018 were identified and vectorized. Basic characteristics of the datasets applied are summarized in Figure 3.

After transforming the maps to the same projection (Unified National Projection, EOV) using ArcGIS 10.4, vineyards were digitized on every map. Although the geodetic precision of the First, Second and Third Military Surveys is from tens to hundreds of meters; the value of these maps cannot be underestimated (Kanianska et al. 2014). On each selected map, vineyards were identified and vectorized as individual polygons.

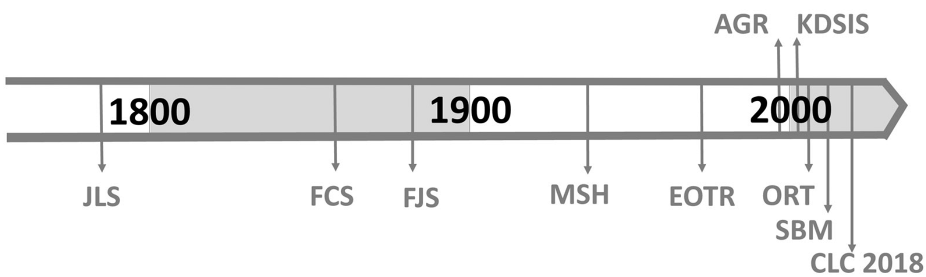
3.2 Identification of geoecological character of vine production sites based on map data

The identified vineyard polygons of each historic dataset were compared with maps of selected geoecological factors such as aspect, slope gradient, elevation, total organic carbon content of the topsoil, thickness of topsoil, pH of topsoil, parent material.

To characterize these geoecological factors the following datasets and mapping methods were applied. Main topographic attribution such as slope and aspect were derived from digitized contours of a topographic map (scale 1:10 000). A digital elevation model (DEM) was created using ArcGIS "Topo to raster" tool. Slope and aspect were derived from DEM by "Slope" and "Aspect" tool. Aspect was characterized by assigning the 4 cardinal and 4 intercardinal directions: north (N), northeast (NE), east (E), southeast (SE), south (S), southwest (SW), west (W), northwest (NW) and without aspect. Slope gradients were classified based on Hungarian agronomy practice (0–5 %; 5–12 %; 12–17 %; 17–

For representation of geoecological diversity (considered as constant)

Sign	Name	Year	Scale	Type of data source
AGR	AGROTOPO	1991	1 : 100 000	General soil and lithology survey
KDSIS	Kreybig Digital Soil Information System	2002	1 : 25 000	Revised soil fertility survey



For delineation of the changes of vine producing areas

Sign	Name	Year	Scale	Type of data source
JLS	Josephinian Land Survey	1784	1 : 28 800	Topographic military land survey
FCS	Franciscan Cadastre Survey	1858	1 : 28 800	Topographic military land survey
FJS	Francisco-Josephinian Survey	1883	1 : 25 000	Topographic military land survey
MSH	Military Survey of Hungary	1941	1 : 25 000	Revised topographic land survey
EOTR	Topographic Map series of EOTR	1972	1 : 10 000	Topographic civilian land survey
ORT	Ortogonal Aerial Photos	2005	1 : 10 000	Orthorectified aerial photograph
SBM	Surveying Base Map	2011	1 : 1 000	Official hungarian land registration dataset
CLC 2018	CORINE Land Cover Map	2018	1 : 50 000	Satellite data

Fig. 3: Map sources for delineation of the geoecological diversity and the changes of vineyard's spatial distribution

25 %; >25 %). Elevation was divided into 25-meter intervals starting from lowest to the highest vineyards (<155; 155–180; 205–230; 255–280; 280–305 and >305 m a.s.l.).

For the characterization of lithological and soil properties two databases were used (*Figure 3*). AGROTOPO database is a map database at a scale of 1:100 000, which allowed us to examine the lithological character of the parent material of soil. Kreybig Digital Soil Information System (KDSIS) is based on the Revised Soil Survey Maps (Kreybig 1:25 0000 soil maps), which were generalized and processed by analogue (Pásztor et al. 2002, Pásztor et al. 2010/a). It was used for evaluating soil organic carbon content, pH, and thickness of fertile topsoil layer. The pH and organic matter content data of KDSIS refer to the topsoil. Topsoil was defined in the field as the layer with the richest organic matter content (Kreybig 1937, Pásztor et al. 2010/b). To evaluate the parent material of the vineyard site the geological-lithological dataset of AGROTOPO was applied. It distinguishes 6 different types of geological formations within the wine district: Mesozoic limestones and dolomites, Tertiary and older sediments, Tertiary volcanics, weathering products of volcanics, Quaternary glacial and alluvial sediments, and loess. Spatial distribution of the lithological data according to this dataset is shown in Figure 2.

All geoecological datasets were converted to raster; soil organic carbon, soil pH and thickness of topsoil were reclassified into four divisions. Break values were defined by the quartiles of KDSIS dataset, considering the extent of the wine district, delimited by boundaries of municipalities. Soil organic carbon content was calculated from organic matter content in KDSIS using the Van Bemmelen factor, and classes were established as follows: <0.7 %; 0.7–1.1 %; 1.1–1.3 %; 1.3–1.7 %. In the case of topsoil pH, the following intervals were used to establish the categories: moderately acidic 5.6–6.0; slightly acidic 6.1–6.5; neutral 6.6–7.3; slightly basic 7.4–7.8.

3.3 Map data processing

The data of the geoecological datasets from AGROTOPO, KDIS, and the DEM model were converted into raster in ArcGIS 10. In the course of data processing, a uniform resolution of 10×10 meters was used for all raster databases. The raster databases describing geoecological data were then intersected with the polygons of the vineyard areas of each period. Based on the sections, we determined the percentage distribution of the categories of geoecological factors typical of the vineyard areas for each period.

Comparison and evaluation of the results was carried out considering the differences of types and resolution of sources maps (Fig. 3). The same was taking into consideration in evaluation of changes in the total extent of vineyards in different maps and times.

We interpret the changes in geoecological conditions as a result of modification in spatial pattern of vine plantations, because there is no information about temporary transformation of soils; therefore, soil characteristics, similarly to lithology and topography, were considered constant. Consequently, map data on geoecological characteristics were applied for the whole study period.

3.4 Soil sampling and analysis

Surface soil sampling sites from a stratified sampling according to the spatial share of lithological constitution within the district were selected randomly to represent the average soil conditions. In total 25 surface soil sampling points were selected in cultivated vineyards; each of them represents approximately 3 km^2 of vineyards within the wine district. Finally, 18 points fell on loose calcareous Tertiary sediments, 6 points on Miocene volcanics and their weathering products, and one point on Quaternary (mixed fluvial, fluvio-glacial and aeolian) sediments. None of the sampling points represents the Mesozoic sedimentary rocks, mostly with high elevation in steep, hilly areas, with negligible spatial extent, and vineyards are scarcely to be found on them.

To characterize the biggest differences between the two most frequent types of the lithological environment of the wine district (Tertiary sediments and Miocene volcanics: covering together 72 % of the district), two soil profiles were excavated down to the parent material and described in detail. One is located on reddish clay, which is a common preglacial weathering product of Miocene volcanics, the other one is over Eocene limestone and marl, partially covered by other calcareous colluvic materials, moving downslope from upper slope sections. Each profile was described in the field (horizons, color, aggregate type, gradient and size, coarse fragments, etc.) according to the standards of the FAO guidelines (FAO 2006), and soil profiles were classified according the WRB (IUSS 2015).

Each surface soil sample was collected by mixing five subsamples taken from a circle with approximately 5-meters in diameter by spade until 15 cm depth, then put into a bucket, mixed and a half kg of it was taken for laboratory analyses. The soil profile samples were taken from each horizon, and analyzed for basic soil characteristics (pH, $CaCO_3$, soil organic carbon (SOC), grain size distribution, coarse fragments). The surface soil samples were analyzed for SOC content, pH, $CaCO_3$, N, P, K content using standardized laboratory methods according to Hungarian Laboratory Standards as follows: the pH was measured in 1 : 2.5 KCl solution with WTW inolab pH7310 electrode, organic carbon content was determined based on the wet oxidation method (Ponomareva & Plotnikova 1980), applying Thermo Scientific Evolution 60s UV-Visible spectrophotometer, $CaCO_3$ content was measured using a volumetric calcimeter (Chaney et al. 1982), P and K were extracted with ammonium-lactate solution, N with KCl solution and measured by Thermo Scientific iCAP 6300 Radial View ICP-OES spectrometer. Grain size distribution was analyzed based on combined wet sieving (2–0.2 mm fractions) and pipette method (<0.2 mm fractions) (Pansu & Gatheyrou 2006).

The topographic, basic geoecological and soil data of the randomly sampled 25 vineyards were evaluated with comparison of the three groups, according to the lithological characteristics of the sampling sites, namely 1 – Miocene volcanics and their weathered material; 2 – Tertiary loose calcareous sediments; 3 – Quaternary loose sediments. No sampling points represent the older, Mesozoic sediments, which can be explained by their subordinate significance in vine production, covered dominantly by forests (Fig. 2).

4 Results

4.1 Temporal changes in the total extent of vineyards

The average extent of vineyards across the studied more than 200 years is 5887 (±721) ha. It was 5346 ha in 1784, and 7413 ha in 2018. Even if we consider the data of 2018 less trustable – since it has the lowest resolution and accuracy (Fig. 3) – and accept the most accurate data from 2011 (5643 ha) as recent, the changes show a slightly increasing tendency over the time (Fig. 4), which is rather atypical in Hungarian wine districts (Feranec et al. 2000, Mód & Simon 2012).

The slightly increasing extent of plantations suggests stability in land use structure. But this stability is rather characteristic only for the total extent of vineyards, since the spatial pattern of production sites with different geoecological backgrounds showed considerable changes, as our results below indicate.

4.2 Changes in the spatial distribution of vineyards influencing the lithology of the terroir

Visible restructuring of plantations based on the parent material's lithological characteristics can be observed during the study periods (Fig. 5a-b). Datasets before 2005 show that the dominant lithological formations of plantations are loose Tertiary sediments (Fig. 5a). These are mostly unconsolidated, calcareous materials (marl, clay, and loose limestones), which together with the Mesozoic calcareous rocks made up 73.6 % of the production area in 1784. Their share fell continuously until recent times

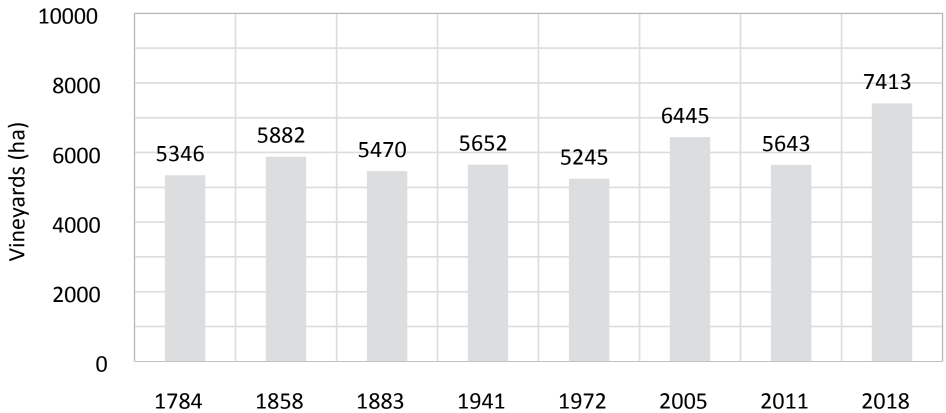


Fig. 4: Changes in the total extent of vineyards over the study period (1784-2018) in Eger Wine District

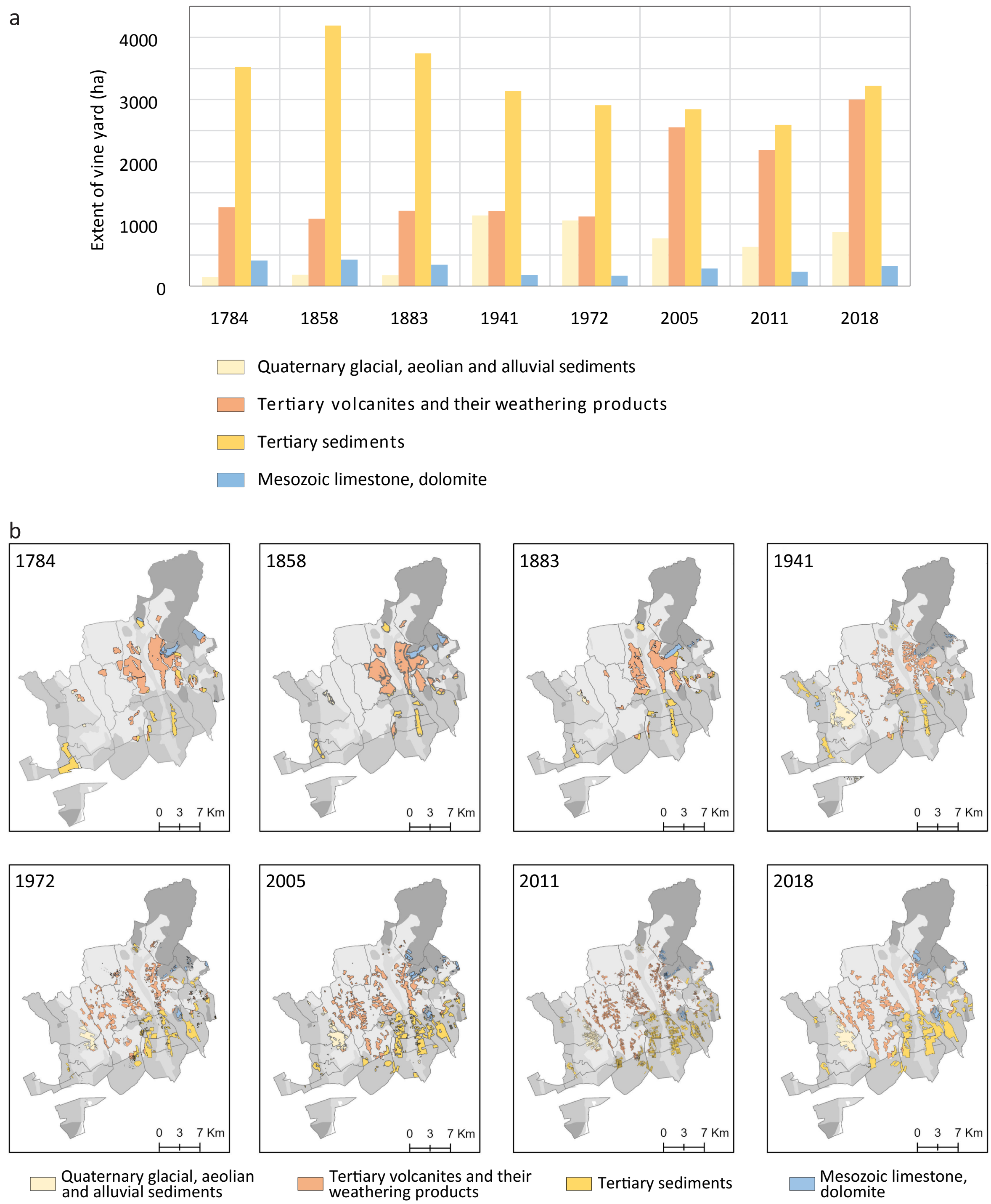


Fig. 5: Distribution of vineyards by the parent material of soils (a) and spatial pattern of changes (b) derived from AGRO-TOPO dataset between 1784 and 2018 in the Eger Wine District

down to 47.8%. In contrary, volcanics and their weathering products occupied 23.6% in 1784, and showed a remarkable increase after 1972, reaching 40.4% in 2018. It is worth noting that Quaternary loose sediments played a negligible role (2.7-3.2%) in production of grape before 1941; their contribution increased until 1972 up to 20.1% and then fell again to 11.7% until recent times (2018) (Fig. 5a).

4.3 Changes in spatial distribution of vineyards influencing the topographic character of the terroir

Generally, the shifting of vineyards to lower elevations and milder slopes could be observed during the study period. Sharp changes can be observed starting from the period between 1883 and 1941. This period includes the time of reconstruction of plantations after the damages of phylloxera disaster, and it shows that in modernization of cultivation lower elevated sites, which are therefore easier to reach and cultivate, were preferred to set the new plantations. Also, the former spatial concentration around Eger was changed in this period, and cultivated vineyards show more spatial dispersion on later maps, meanwhile shifting south from the former production sites (Fig. 5b).

The plantations in the lowest elevation classes (<155 m a.s.l.) were most extent in 1941 (10.3 %, 580 ha), while in earlier and later datasets they were represented by lower rates and extent (in 1784: 8.5 %, 458 ha; in 2018: 4.3 %, 321 ha). In the highest two elevation classes (280-305 and >305 m a.s.l.) was 11.8 % (635 ha) of the vineyards belonging in 1784, but their share is less than half of that value recently (2018: 4.8 %, 356 ha). The most remarkable increase was possible to observe in the elevation class 155-180 m a.s.l., from 7.4 % (395 ha) in 1784, to 21.2 % (1571 ha) in 2018. Also, there was an increase in the share of the class 180-205 m a.s.l. (18.0 %, 966 ha to 25.6 %, 1897 ha), but in all the classes at higher elevation there was continuous decrease detectable (Fig. 6).

Slope gradient changes are also remarkable showing generally a decrease in the share of steeper slope classes over the time (Fig. 7). Until 1941 in all datasets approximately 5 % of vineyards belonged to the steepest two classes (gradient 17-25 % and >25 %), while these classes disappeared almost completely after 1941 from vineyards. Slopes with a gradient of 12-17 % represented 11.1 % of vineyards (593 ha) in 1784, and their share decreased to 1.5 % (111 ha) by 2018. Still the share of vineyards in slope gradient class 5-12 % decreased during the study period from 45.2 % in 1784 (2419 ha) to 33.1 % in 2018 (2453 ha), even if their extent increased. Extension of vineyards belonging to the gradient class of <5 % is striking (Fig. 7) 2044 ha (38.2 %) in 1784 increased to 4826 ha (65.1 %) by 2018. Like the elevation, advantages of smaller slope gradients gained importance after the mechanization of cultivation. Otherwise, smaller slope gradients contribute less to the increase of insolation energy and improving the sugar content of grapes in higher latitude production sites, like the studied one.

4.4 Changes in the spatial distribution of vineyards that influence basic soil properties of the terroir

The spatial reorganization of vineyards also changed the distribution of vineyards with different soil pH, different soil organic carbon concentration in the surficial soil horizon, and soil depth (depth of organic rich soil horizons) (Fig. 8).

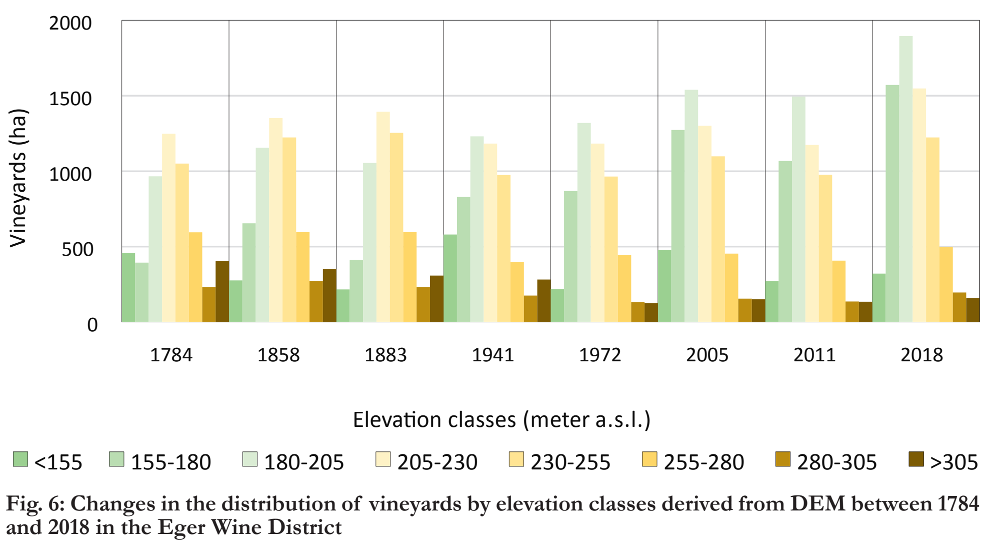


Fig. 6: Changes in the distribution of vineyards by elevation classes derived from DEM between 1784 and 2018 in the Eger Wine District

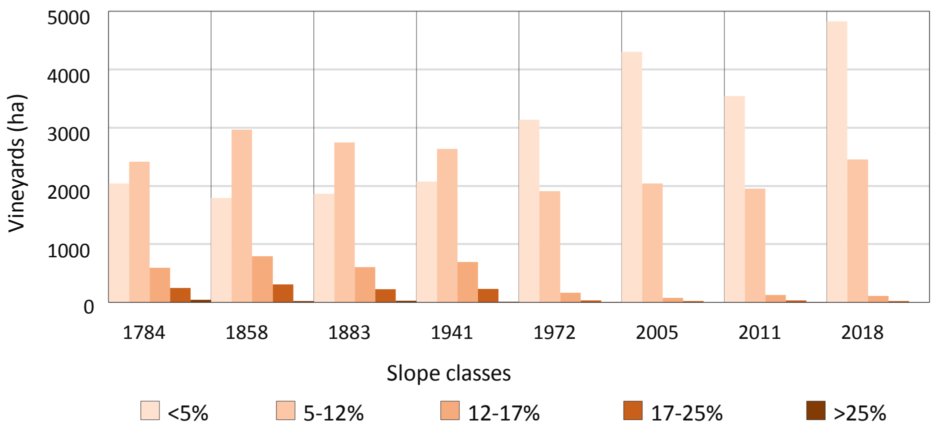


Fig. 7: Changes in distribution of vineyards by slope gradient classes derived from DEM between 1784 and 2018 in the Eger Wine District

Concerning the pH, the increase of vine production on slightly acidic soils and a decrease on neutral soils is remarkable; 37 % of the production sites (1996 ha) in 1784 were on slightly acidic soils which increased to 63 % (4660 ha) in 2018, while 38 % (2031 ha) of the production was on neutral soils in 1784, which decreased to 13 % (986 ha) in 2018. Furthermore, the increase of vineyards on moderately acidic soils, and a decrease on slightly basic soils was detectable (Fig. 8a).

According to the topsoil SOC content, the growth of production sites with higher topsoil SOC content and a decrease of classes with lower SOC content were detected. The share of production sites with the highest SOC content (1.3-1.7 %) increased from 12 % (645 ha) to 30 % (2205 ha) from 1784 to 2018, respectively. At the same time, the share and extent of vineyards with lower topsoil SOC concentration (1.1-0.7 %, and <0.7 %) decreased from 39 % (2074) and 32 % (1717) to 20 % (1472 ha) and 20 % (1468 ha) respectively (Fig. 8b).

Regarding the distribution of vineyards based on soil depth (see definition in methods chapter, at KDSIS dataset), the share of soils with the deepest (>120 cm) fertile soil layer increased remarkably, from 34 % (1834 ha) in 1784 to 45 % (3309 ha) in 2018. In contrast, the share of soils with a shallow (<68 cm) fertile layer decreased from 9 % (487 ha) in 1784 to 4 % (262 ha) in 2018. Compared to this, other soils with medium depth of fertile soil layers showed rather just small fluctuation (Fig. 8c).

To represent lithological and topographic extremes within the production sites, two soil profiles were selected, both in vineyards derived from the most abundant two types of different parent materials and landforms within the production sites:

1) Tertiary sediments, on elevated, steep terrain, represented by soil Profile 1, Nagy-Eged
2) Volcanics and derivates, on lower, flat terrain, represented by soil Profile 2, Kőlyuktető

The share of the two groups represented by these profiles changed remarkably over the study period among the vine production sites areas.

For the first type of production sites, calcareous parent material is characteristic on steep slopes and at higher elevation, with visible remarks of constant and strong soil erosion. The topsoil layer is incompletely leached, decarbonated, organic enriched, and the fertile topsoil layers are not very deep, with increasing amount of skeletal parts with depth (Tab. 1, Tab. 2). The described soil profile is classified as Calcairc-Skeletic-Cambic-Rendzic Phaeozem (Aric, Colluvic, Loamic) (Fig. 9). Due to the machinery cultivation and deep plough, Cambic and Mollic horizons are mixed, and occur with irregularly broken lower shape. In many parts of surface samples, despite the presence of calcaric parent material, the topsoil samples contain no, or very low amount of carbonates as a result of leaching processes during the soil development, anyway, colluvial processes bring constantly fresh, still not decarbonated regolith near the surface; hence carbonate content of the topsoil in this type of soils shows very high variability. Furthermore, for the topsoil samples, low N, but higher K and P status, and neutral to slightly acidic pH were found.

The second representative type has clay rich weathered volcanic rocks as parent material on slightly sloping and flat areas. The type of clay minerals allowed the development of shrink-swell characteristic, resulting in Vertisols (Fig. 9). Deep, or-

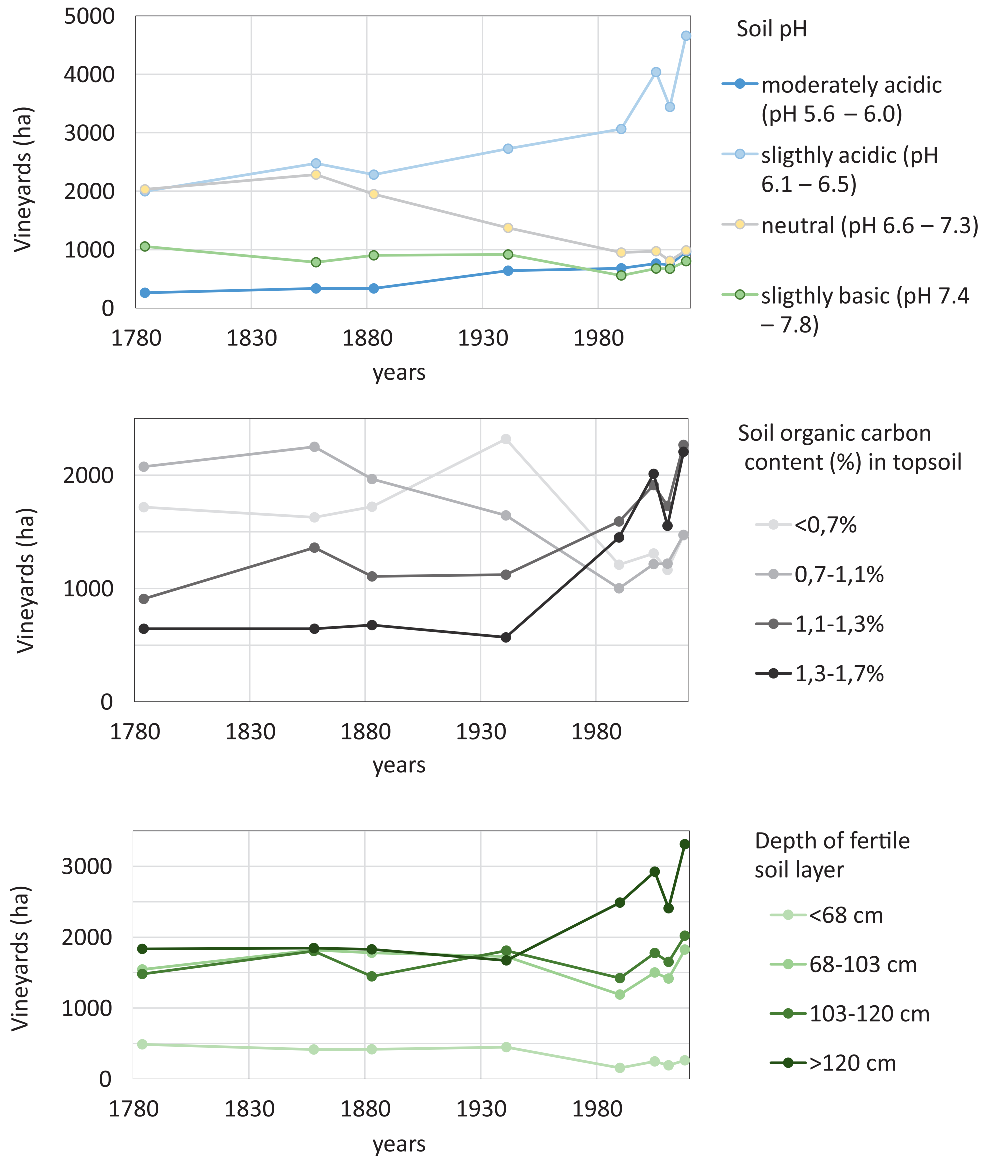


Fig. 8: Changes in distribution of vineyards by a) soil pH, b) SOC content, and c) the depth of fertile soil layer based on the KDSIS between 1784 and 2018 in the Eger Wine District

ganic rich Mollic horizons and stagnic properties as results of higher clay content in deeper horizons are typical for these soils. The representative profile was classified as Pellic Vertisol (Mollic, Amphistagnic). Surface samples from this type showed better N, as well as good P and K status with neutral-slightly acidic pH. N content proved to be low in both profiles (5.8 $mg \cdot kg^{-1}$ in the Phaeozem, and 1.1 $mg \cdot kg^{-1}$ in the Vertisol), but P content showed different levels of concentration in the cultivated layer of the two representative profiles (193.8 $mg \cdot kg^{-1}$ and 24.0 $mg \cdot kg^{-1}$, respectively). Field characteristics, horizonation, diagnostics and basic physico-chemical data of both representative profiles are shown in Table 1 and Table 2.

To prove if there are relevant differences between soils derived from different parent materials, the data of randomly selected surface soil sampling from 25 vineyards were statistically analyzed. The data from the 18 sampling sites from the cultivated layers over loose Tertiary sediments were compared to the data of the 6 sampling sites on volcanics and weathered volcanic materials using independent samples Mann-Whitney U-test. Differences, depicted in boxplots in Figure 10,

Tab. 1: Field characteristics and diagnostics of the two soil profiles representing the extremes of vineyards

Hori-zons	Depth (cm)	Structure Gradient	Type	Size	Munsell color (moist)	Diagnostics Properties, materials	Horizons
			Profile 1 - NAGY-EGED				
Ap	0-10	moderate	subangular blocky/ granular	fine, very fine	10YR 3/2	Colluvic material, Calcaric material	Mollic horizon
Ah/ Bw	10-35	moderate	subangular blocky	fine, very fine	10YR 4/3	Colluvic material, Calcaric material	Mollic horizon/ Cambic horizon
Ah/ Bw	10-35	moderate	subangular blocky	fine, very fine	7.5YR 5/3	Colluvic material, Calcaric material	Cambic horizon
Bw	35-55	moderate	subangular blocky	fine, very fine	7.5YR 5/4	Colluvic material, Calcaric material	-
C	55-85	weak	subangular blocky	fine, very fine	7.5YR 6/4	Calcaric material	-
			Profile 2 - KŐLYUKTETŐ				
Ap	0-35	strong	angular blocky	fine	10YR 3/1	Artefacts (few)	Mollic horizon
Ag	35-55	strong	subangular blocky	fine	10YR 3/1	Stagnic properties	Mollic horizon
Big	55-75	strong	subangular blocky, wedge-shaped	fine	10YR 3/2	Slickensides, Stagnic properties	Vertic horizon
BCi	75-110	strong	angular blocky	fine-medium	10YR 3/3	Slickensides	Vertic horizon

Tab. 2: Physico-chemical characteristics of the two soil profiles representing the extremes of vineyards

Hori-zons	Depth (cm)	Coarse fraction % >2 mm	pH (KCl)	SOC in fine earth $g \cdot kg^{-1}$	$CaCO_3$ in fine earth % (m/m)	P_2O_5 $mg \cdot kg^{-1}$	N (NO_3^- +NO_2^-) $mg \cdot kg^{-1}$	grain size distribution in fine earth (%) sand 2-0.05 mm	silt 0.05-0.002 mm	clay <0.002 mm	textural class of fine earth	Bulk density $g \cdot cm^{-3}$
					Profile 1 - NAGY-EGED							
Ap	0-10	35.5	7.3	18.5	17.8	194	6	28.5	37.7	33.8	CL	1.42
Ah/Bw	10-35	36.7	7.3	17.3	19.4	74	6	30.5	34.5	35.0	CL	1.42
Ah/Bw	10-35	43.5	7.5	13.9	4.0	43	6	29.9	40.2	29.9	CL	1.46
Bw	35-55	46.7	7.7	8.3	62.2	37	6	36.8	36.0	27.2	CL	1.45
C	55-85	57.1	7.9	8.4	63.0	31	4	34.4	41.8	23.8	L	1.43
					Profile 2 - KŐLYUKTETŐ							
Ap	0-35	2.0	5.3	10.3	0	24	1	13.7	41.0	45.3	SiC	1.32
Ag	35-55	0.0	5.4	6.5	0	<10	<1	11.3	37.6	51.1	C	1.11
Big	55-75	0.0	5.4	6.8	0	<10	1	10.3	37.7	52.0	C	1.02
BCi	75-110	0.0	5.5	4.6	0	<10	<1	10.0	35.7	54.3	C	1.02

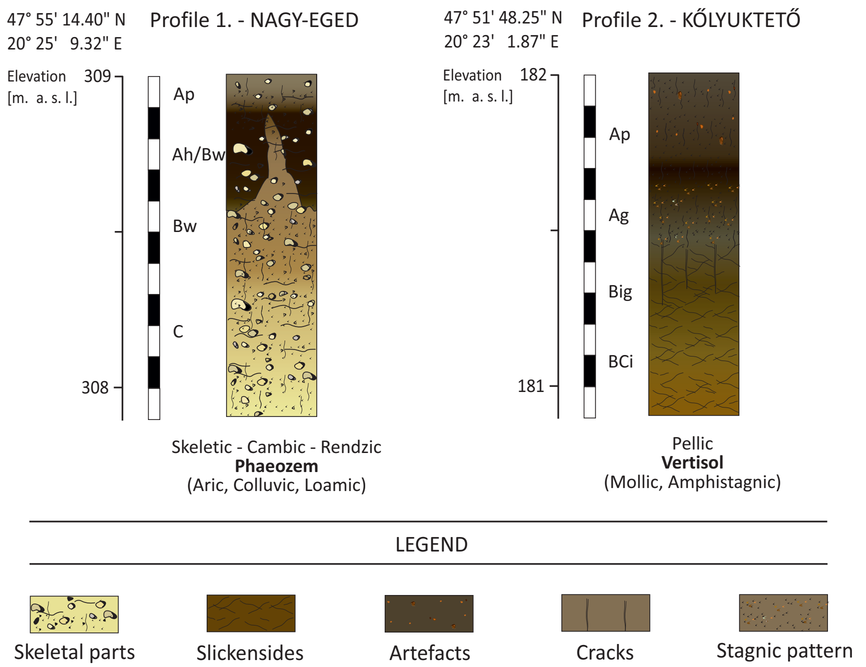


Fig. 9: Soil profile horizonation and WRB classification of the representative soil profiles on the two dominant lithological types of grape production in Eger Wine District

proved to be of no significance in either of the topsoil variables (pH, SOC, $CaCO_3$, P, N, K contents). The single sampling site on Quaternary loose sediments could not be involved in the statistical comparison.

The lack of statistically relevant differences in surface soil characteristics is indicating that extremes, as shown by the two soil profiles, which are representing the different lithological constitutions, could not be considered typical, they are much more showing the possible extremes of the soils. However, average soils derived from different parent materials do not have statistically different characters in the ploughed layer. A more responsible factor for the soil differences found in comparison of soil map data and historic maps of vineyards (see 4.4 section: in pH, depth of fertile layer, and SOC content of soil) might be the topographic position (slope, elevation) and not the parent material.

5 Discussion and conclusions

During the last 250 years viticulture in Hungary was fundamentally influenced by three main events and processes: (1) the phylloxera epidemic at the end of the 19th century; (2) the 'socialist' political and economic transformation after the Second World War; and (3) the political changes in 1989-90.

After it had destroyed most of the western European vineyards, the phylloxera epidemic reached Hungary in the last decades of the 19th century and destroyed more than half of the grapevine plantations in the country. Although the effect of the epidemic was catastrophic in the Eger wine region, too, contrary to some other areas where wine grape was not the only dominant crop supporting the farmers' subsistence (e.g., Selešťany, now in Slovakia, see Štefunková & Hanušin 2019) or mode of living could be changed due to the possibility of employment in industry and/or mining (e.g., Miskolc-Diósgyőr, see Sütő 2013, Sütő et al.2021), the re-plantations began within a relatively short time and wine production here revived (Kozári 1982). By the period between the two world wars, the area of the vineyards reached their former extent (see Fig. 4). Indeed, the revival of vineyards was, at least partly, the result of the fact that the Eger region did not belong to the most dynamically industrializing ones at that time; therefore, the labor-attraction effect of the industry was quite limited. Since the insect does not prefer sandy soils, a consequence of the phylloxera devastation was that plantations established on sandy Quaternary sediments were represented in a much greater extent than previously (Fig. 5a).

The total area of vineyards, although it has varied from time to time, today is larger than it was in the late 18th century, however, their geographic po-

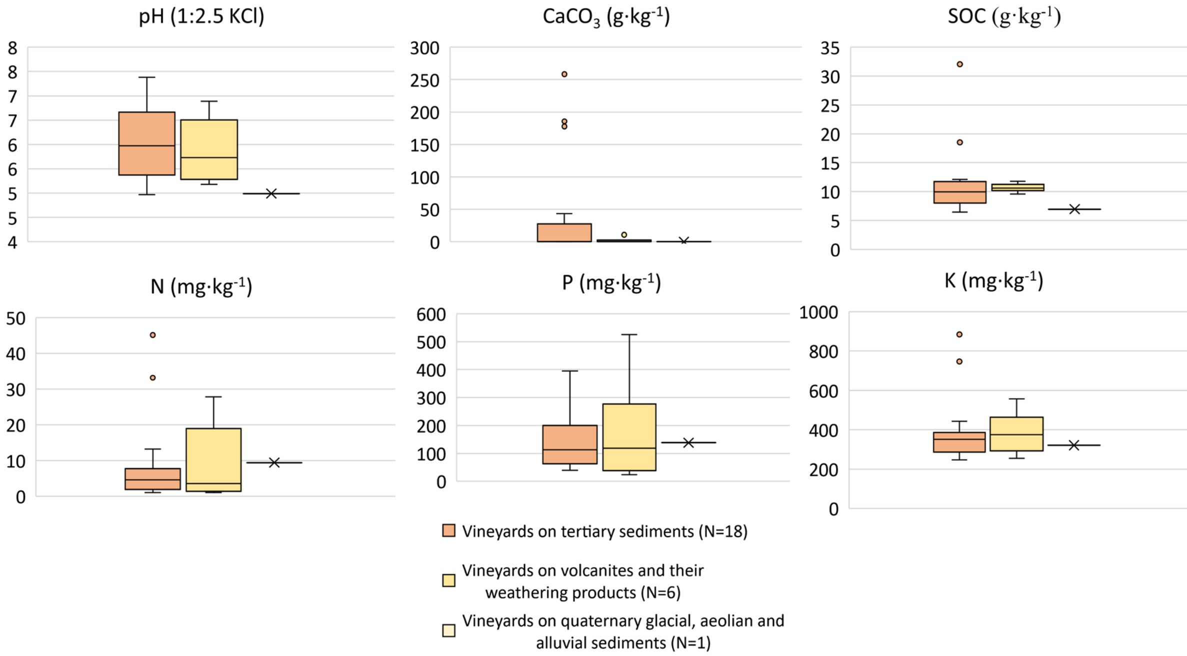


Fig. 10: Comparison of geoecological types of wine plantations based on topsoil (0-10 cm) characteristics from surface samples in the Eger Wine District

sition has changed considerably. Until the phylloxera epidemic the compact core areas were near Eger city, however, in the 20th century a continuous shift toward west and south can be observed, and, as a consequence, the predominance of the vineyards of Eger city within the region has gradually decreased (Fig. 5b). The shifting of vineyards in space meant lithologically, that the ratio of vineyards on Tertiary volcanics and their weathering products increased (particularly during the last two or three decades), while on Tertiary sediments (clays, clayey marls, etc.) decreased (Fig. 5b). As a result of this spatial rearrangement, the average elevation of the plantations has become lower and lower; accordingly, the characteristic slope of the vineyards also decreased, and recently more than 50 % of them belong to the lowest (< 5 %) slope class, while viticulture on slopes steeper than 17 % practically disappeared after WWII. Although this process began after the phylloxera epidemic, it accelerated in the socialist era due to mechanized large-scale viticulture which was one of the consequences of collectivization, and this process seems to continue after the political changes of 1989 (Fig. 6 & 7). The shift of vineyards from higher altitudes and steeper slopes to lower altitudes and flatter areas, and, as a result, the reduction and, in some cases, the cessation of traditional viticulture was a general trend in European grape-growing landscapes in the second half of the 20th century, from Tuscany (Agnoletti et al. 2015) to Hungary (Sütő et al. 2017, Incze & Novák 2016), from Slovakia (Lieskovský et al. 2015) to Greece (Petanidou et al. 2008).

Transformation of the areal pattern in the last 150 years is also reflected in the distribution of the areas of vineyards in the settlements belonging to the Eger Wine District. As mentioned above, vineyards in Eger city have always played an eminent role in the vine production of the district, however, the proportion of their area continuously decreased in the last 150 years. This process has been closely related to the growing population and, consequently, the increasing built-up area of Eger city, the only real urban settlement of the wine district. From 1870 to 1960 population of Eger moderately and steadily grew at a rate characteristically less than 1 %/y, (20510 and 38610 inhabitants in 1870 and 1960, respectively); from 1960 to 1980, however, the annual rate of population growth exceeded 2 %, moreover, starting from a higher base (in the 1980s the population of Eger stagnated, and since then it has been moderately decreasing) (http://nepesseg.com/heves/eger). Accordingly, the extent and proportion of the vineyards in Eger slowly but continuously decreased by WWII (from more than 60 % in 1883 to approximately 30 % in 1972), and their extent has dramatically decreased not only during the socialist era but also during post-socialist three decades (less than 25% in 2011); nevertheless, they dominate the wine district even today.

Generally, the changes above resulted in an increase of higher share of soils with deeper fertile layers, higher organic carbon concentration, lower pH among the production sites after 1941. In our consideration it is related to the fact that the importance of production sites over calcareous sediments, and parent materials with volcanic origin changed remarkably after this time (Fig. 5). Shifting of vine production into the direction of agriculturally more favorable sites, their spatial dispersion to south and west from Eger changed their former concentration around the town. It has complex backgrounds as shown above, and maybe it facilitates the production, but rather questionable from the optimization of land use and wine quality.

Vineyards, subjected to changes of wine consumers habits, investment opportunities (Varga 2010), technological conditions, cultivation practices, and climate change were especially affected by land use changes across the past two centuries. Historic datasets and maps proved to be useful tools to identify these changes (Incze & Novák 2016).

The comparison of the spatial changes of vineyards identified in historic maps with models and datasets describing the geoecological conditions of the production sites allowed us to analyze the possible changes of the abiotic compartments of the terroir. One result of these spatial changes is that vineyards shifted to gentler slopes and to lower elevations, similarly to many other wine districts in Europe (Stanchi et al. 2013, Novák & Incze 2016). Among climatic conditions, where the topography significantly affects the irradiation and temperature during the vegetation period, these topographic changes may influence the quality of grape and wine. With application of already existing datasets, it was possible to point out how the spatial changes of vineyards changed the composition of lithological and pedological characteristics of the production areas. The shifting of production towards more fertile soils can raise questions of land use optimization (Heaton & Merenlender 2000, Merenlender 2000), if vineyards occupy sites of other crops demanding higher soil fertility, especially, but also, this may affect the components of a terroir.

Our finding, that changes in the share of production sites with different lithology had no relevant influence on the nutrient supply of the surface soil layers within the terroir, has limited validity. Once, our comparison of production sites with different lithology was restricted to the cultivated topsoil, but especially in case of grapevine, deeper soil layers may contribute significantly to quality and productivity (Becker 1987, Mendes et al 2021), finally to the terroir. Further, in the case of other wine districts, with higher geodiversity, even topsoil characteristics may be more variable, therefore spatial changes of vineyards may result in relevant alteration of the geoecological character of the production sites.

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References

Agnoletti M, Conti L, Frezza L, Santoro A (2015) Territorial analysis of the agricultural terraced landscapes of Tuscany (Italy): Preliminary results. *Sustainability* 7: 4564–4581. https://doi.org/10.3390/su7044564

Arnó J, Rosell JR, Blanco R, Ramos MC, Martínez-Casasnovas JA (2012) Spatial variability in grape yield and quality influenced by crop and soil nutrition characteristics. *Precision Agriculture* 13: 393–410. https://doi.org/10.1007/s11119-011-9254-1

Basso M (2019) Land-use changes triggered by the expansion of wine-growing areas: A study on the Municipalities in the Prosecco's production zone (Italy) *Land Use Policy* 83: 390–402. https://doi.org/10.1016/j.landusepol.2019.02.004

Baumann M, Kuemmerle T, Elbakidze M, Ozdogan M, Radeloff VC, Keuler NS, Prishchepov AV, Kruhlov I, Hostert P (2011) Patterns and drivers of post-socialist farmland abandonment in Western Ukraine. *Land Use Policy* 28 : 552–562. https://doi.org/10.1016/j.landusepol.2010.11.003

Becker N (1987) Influence des facteurs du milieu sur le développement des vignes, la maturation des baies et les paramétres de la production, résultat d'une enquete sur 12 parcellas Pinot gris en pays de bade méridional. *Physiologie de la vigne. 3e Symposium International sur la Physiologie de la Vigne. 24–27 Juin 1986:* 339–346. Bordeaux.

Bernetti I, Menghini S, Marinelli N, Sacchelli S, Alampi Sottini V (2012) Assessment of climate change impact on viticulture: economic evaluations and adaptation strategies analysis for the Tuscan wine sector. *Wine Economics and Policy* 1: 73–86. https://doi.org/10.1016/j.wep.2012.11.002

Bicik I, Jelecek L, Stepanek V (2001) Land-use changes and their social driving forces in Czechia in the 19th and the 20th centuries. *Land Use Policy* 18: 65–73. https://doi.org/10.1016/S0264-8377(00)00047-8

Bonfante A, Basile A, Langella G, Manna P, Terribile F (2011) A physically oriented approach to analysis and mapping of terroirs. Geoderma 167–168: 103–117. https://doi.org/10.1016/j.geoderma.2011.08.004

Bonfante A, Monaco E, Langella G, Mercogliano P, Bucchignani E, Manna P, Terribile F (2018) A dynamic viticultural zoning to explore the resilience of terroir concept under climate change. *Science of the Total Environment* 624: 294–308. https://doi.org/10.1016/j.scitotenv.2017.12.035

Borelli P, Robinson DA, Fleischer LR, Lugato E, Ballabio C, Alewell C, Meusberger K, Modugno S, Schutt B, Ferro V, Bagarello V, Van Oost K, Montanarella L, Panagos P (2017) An assessment of the global impact of 21st century land use change on soil erosion. Nature Communications 8: 1–13. https://doi.org/10.1038/s41467-017-02142-7

Boros L (2008) Development and types of uncultivated land in Tokaj-Hegyalja Wine Region. *Földrajzi Közlemények* 132: 145–156 (in Hungarian).

Boros L (2011) Temporal and spatial changes in vineyards of Tokaj-Hegyalja during the 18–20. century) *Földrajzi Közlemények* 135: 445–458

Bürgi M, Hersperger AM, Schneeberger N (2004) Driving forces of landscape change – current and new directions. *Landscape Ecology* 19: 857–868. https://doi.org/10.1007/s10980-004-0245-8

Carbone A, Quici L, Pica G (2019) The age dynamics of vineyards: Past trends affecting the future. *Wine Economics and Policy* 8: 38–48. https://doi.org/10.1016/j.wep.2019.02.004

Chaney RC, Slonim SM, Slonim SS (1982) Determination of calcium carbonate content in soils. Chaney RC, Demars KR (eds) *Geotechnical properties, behavior, and performance of calcareous soils. American Society for Testing and Materials:* 3–16. Philadelphia. https://doi.org/10.1520/STP28907S

Constantini EAC, Lorenzetti R, Malorgio G (2016) A multivariate approach for the study of environmental drivers of wine economic structure. *Land Use Policy* 57: 53–63. https://doi.org/10.1016/j.landusepol.2016.05.015

Csorba P (2020) Basic principles of the landscape division in the new National Atlas of Hungary. *GeoMetodika* 4: 5–17. (in Hungarian, with english abstract). https://doi.org/10.26888/GEOMET.2020.4.1.1

Czigány SZ, Fábián SÁ, Nagy G, Novák TJ (2018) Soils of the southern slopes of the Villány Hills, SW Hungary. Świtoniak M, Charzyński P (eds) *Soil sequences Atlas II:* 187–201. Torun.

Czigány SZ, Novák TJ, Pirkhoffer E, Nagy G, Lóczy D, Dezső J, Fábián SÁ, Świtoniak M, Charzyński P (2020) Application of a topographic pedosequence in the Villány Hills for terroir characterization. *Hungarian Geographical Bulletin* 69: 245–261. https://doi.org/10.15201/hungeobull.69.3.2

Dobor L, Barcza Z, Hlásny T, Havasi Á, Horváth F, Ittzés P, Bartholy J (2014) Bridging the gap between climate models and impact studies: The FORESEE Database. Geoscience Data *J* 2:1–11. https://doi.org/10.1002/gdj3.22

Dobos A (2012) Reconstruction of Quaternary landscape development with geomorphological mapping and analysing of sediments at the Cserépfalu Basin (the Bükk Mts., Hungary). *Geomorphologica Slovaca et Bohemica* 1: 7–22.

Dobos A, Nagy R, Molek,Á (2014) Land use changes in a historic wine region and their connections with optimal land-use: a case study of Nagy-Eged Hill, Northern Hungary. *Carpathian Journal of Earth and Environmental Sciences* 9: 219–230.

Dövényi Z (ed) (2010) Magyarország kistájainak katasztere (Inventory of microregions in Hungary). Budapest.

FAO (2006) Guidelines for soil description. Rome.

Feranec J, Šúri M, Ot'ahel' J, Cebecauer T, Kolář J, Soukup T, Nitica C (2000) Inventory of major landscape changes in the Czech Republic, Hungary, Romania and Slovak Republic 1970s – 1990s. *International Journal of Applied Earth Observation and Geoinformation* 2: 129–139. https://doi.org/10.1016/s0303-2434(00)85006-0

Fraga H, García de Cortazar Atauri I, Malheiro AC, Santos JA (2016) Modelling climate change impacts on viticultural yield, phenology and stress conditions in Europe. *Global Change Biology* 22: 3774–3788. https://doi.org/10.1111/gcb.13382

Gerard F, Petit S, Smith G, Thomson A, Brown N, Manchester S, Wadsworth R, Bugar G, Halada L, Bezák P, Boltiziar M, De badts E, Halabuk A, Mojses M, Petrovic F, Gregor M, Hazeu G, Mücher CA, Wachowicz M, Huitu H, Tuominen S, Köhler R, Olschofsky K, Ziese H, Kolar J, Sustera J, Luque S, Pino J, Pons,X, Roda,F, Roscher M, Feranec J (2010) Land cover change in Europe between 1950 and 2000 determined employing aerial photography. *Progress in Physical Geography* 34: 183–205. https://doi.org/10.1177/0309133309360141

González PA, Parga-Dans E. Macías Vázquez A (2017) The political economy of wine: How terroir and intra-sector dynamics affect land use in Spain. *Land Use Policy* 66: 288–292. https://doi.org/10.1016/j.landusepol.2017.04.048

Gyalog L (ed) (2005) Explanations to the Surface Geological Map of Hungary in 1:100 000 Scale. Budapest (in Hungarian).

Heaton E, Merenlender AM (2000) Modeling vineyard expansion, potential habitat fragmentation. *California Agriculture* 54: 12–19. https://doi.org/10.3733/ca.v054n03p12

Iglesias A, Quiroga S, Moneo M (2012) From climate change impacts to the development of adaptation strategies: Challenges for agriculture in Europe. Climatic Change 112: 143–168. https://doi.org/10.1007/s10584-011-0344-x

Incze J, Novák TJ (2016) Identification of extent, topographic characteristics and land abandonment process of vineyard terraces in the Tokaj-Hegyalja wine region between 1784 and 2010. *Journal of Maps*. https://doi.org/10.1080/17445647.2016.1195295

IUSS Working Group WRB (2015) World reference base for soil resources 2014. Update 2015 International soil classification system for naming soils and creating legends for soil maps. *World Soil Resources Report* 106. Rome.

Jones GV (2006) Climate and terroir: Impacts of climate variability and change on wine. Macqueen RW, Meinert LD (eds) Fine wine and terroir - the geoscience perspective. St. John's, Newfoundland.

Jordan G, van Rompaey A, Szilassi P, Csillag,G, Mannaerts C, Woldai T (2005) Historical land use changes and their impact on sediment fluxes in the Balaton basin (Hungary). *Agriculture, Ecosystems and Environment* 108: 119–133. https://doi.org/10.1016/j.agee.2005.01.013

Kanianska R, Kizeková M, Novácek J, Zeman M (2014) Land-use and land-cover changes in rural areas during different political systems: A case study of Slovakia from 1782 to 2006. *Land Use Policy* 36: 554–566. https://doi.org/10.1016/j.landusepol.2013.09.018

Kiss A, Barta K, Sümeghy Z, Czinege A (2005) Historical land use and anthropogenic features: A case study from Nagymaros. *Acta Climatologica et Chorologica Universitatis Szegediensis* 38–39: 111–124.

Kottek M, Grieser F, Beck C, Rudolf B, Rubel F (2006) World map of the Köppen-Geiger climate classification up-dated. *Meteorologische Zeitschrift* 15: 259–263. https://doi.org/10.1127/0941-2948/2006/0130

Kozári J (1982) Adalékok a filoxéra-pusztításnak Eger város gazdaságára gyakorolt hatásához (Data to the effect of the Phylloxera-devastation on the economy of the city of Eger). *Acta Academiea Paedagogicae Agriensis: nova series* 16: 129-140. (in Hungarian).

Kreybig L (1937) A Magyar Királyi Földtani Intézet talajfelvételi, vizsgálati és térképezési módszere (Die Methode der Bodenkartierung der Kgl. Ung. Geol. Anstalt). *Magyar Királyi Földtani Intézet Évkönyve* 31: 147–244. (in Hungarian with German abstract)

Kuemmerle T, Hostert P, Radeloff VC, van der Linden S, Perzanowski K, Kruhlov I (2008) Cross-border comparison of post-socialist farmland abandonment in the Carpathians. *Ecosystems* 11: 614–628. https://doi.org/10.1007/s10021-008-9146-z

Kuemmerle T, Erb K, Meyfroidt P, Müller D, Verburg PH, Estel S, Haberl H, Hostert P, Jepsen MR, Kastner T, Levers Ch, Lindner M, Plutzar C, Verkerk PJ, van der Zanden EH, Reenberg A (2013) Challenges and opportunities in mapping land use intensity globally. *Current Opinion in Environmental Sustainability* 5: 484–493. https://doi.org/10.1016/j.cosust.2013.06.002

Lieskovský J, Bezák P, Špulerová J, Lieskovský T, Koleda P, Dobrovodská M, Bürgi M, Gimmi U (2015) The abandonment of traditional agricultural landscape in Slovakia – Analysis of extent and driving forces. *Journal of Rural Studies* 37: 75–84. https://doi.org/10.1016/j.jrurstud.2014.12.007

Lieskovsky J, Kanka R, Bezák,P, Stefunková D, Petrovic F, Dobrovodská M (2013) Driving forces behind vineyard abandonment in Slovakia following the move to a market-oriented economy. *Land Use Policy* 32: 356–365. https://doi.org/10.1016/j.landusepol.2012.11.010

Mendes MP, Matias M, Gomes RC, Falcão AP (2021) Delimitation of low topsoil moisture content areas in a vineyard using remote sensing imagery (Sentinel-1 and Sentinel-2) in a Mediterranean-climate region. *Soil & Water Research* 16: 85−94. https://doi.org/10.17221/101/2019-SWR

Merenlender AM (2000) Mapping vineyard expansion provides information on agriculture and the environment. *California Agriculture* 54:7–12. https://doi.org/10.3733/ca.v054n03p7

Mód L, Simon A (2012) Wine districts, wine regions, vineyards – the construction and representation of borders in the Hungarian wine culture. *Acta Ethnographica Hungarica* 57: 57–90. https://doi.org/10.1556/AEthn.57.2012.1.7

Molnár C, Molnár Z, Barina Z, Bauer N, Biró M, Csiky J, Fekete G, Horváth A, Király BG, Purger D, Schmidt D, Sramkó G, Bodonczi L, Csathó AI, Deák ÁJ, Harmos K, Isépy I (2008) Vegetation-based landscape regions of Hungary. *Acta Botanica Hungarica* 50 (Suppl.): 47–58. https://doi.org/10.1556/ABot.50.2008.Suppl.4

Munteanu C, Kuemmerle T, Boltiziar M, Butsic V, Gimmi U, Halada L, Kaim D, Király G, Konkoly-Gyuró É, Kozak J, Lieskovsky J, Mojses M, Müller D, Ostafin K, Ostapowicz K, Shandra O, Stychl P, Walker S, Radeloff VC (2014) Forest and agricultural land change in the Carpathian region - A meta-analysis of long-term patterns and drivers of change. *Land Use Policy* 38: 685–697. https://doi.org/10.1016/j.landusepol.2014.01.012

Novák TJ, Incze J, Spohn M, Glina B, Giani L (2014) Soil and vegetation transformation in abandoned vineyards of the Tokaj Nagy-Hill. *Catena* 123: 88–89. https://doi.org/10.1016/j.catena.2014.07.017

Novák TJ, Incze J (2014) Retaining walls of abandoned vineyard terraces on Tokaj Nagy Hill. *4D Journal of Landscape Architecture and Garden Art* 35: 20–35

Novák TJ, Molnár M, Buró B (2018) Reconstruction of soil carbon redistribution processes along a hillslope section in a forested area. *Radiocarbon* 60: 1413–1424. https://doi.org/10.1017/RDC.2018.94

Nyizsalovszki R, Fórián T (2007) Human impact on the Landscape in the Tokaj Foothill Region. *Supplementi di Geografia Fisica e Dinamica Quaternaria* 30, 219–224.

Pansu M, Gatheyrou J (2006) Handbook of soil analysis. Heidelberg, Berlin. https://doi.org/10.1007/978-3-540-31211-6

Pásztor L, Szabó J, Bakacsi Z (2002) Compilation of a national 1:25,000 scale digital soil information system in Hungary. Vanlauwe B (ed) *Soil science: Confronting new realities in the 21st century: Proceedings of the 17th World Congress of Soil Science Bangkok:* 949–957.

Pásztor L, Szabó J, Bakacsi Z (2010/a) Digital processing and upgrading of legacy data collected during the 1:25.000 scale Kreybig soil survey. *Acta Geodaetica et Geophysica Hungarica* 45: 127–136. https://doi.org/10.1556/AGeod.45.2010.1.18

Pásztor L, Szabó J, Bakacsi Z (2010/b) Application of digital Kreybig soil information system for the delineation of naturally handicapped areas in Hungary. *Agrokémia és Talajtan* 59: 47–56. https://doi.org/10.1556/agrokem.59.2010.1.6

Petanidou T, Kizos T, Soulakellis N (2008) Socioeconomic dimensions of changes in the agricultural landscape of the Mediterranean basin: A case study of the abandonment of cultivation terraces on Nisyros Island, Greece. *Environmental Management* 41: 250–266. https://doi.org/10.1007/s00267-007-9054-6

Ponomareva VV, Plotnikova TA (1980) Gumus i Pochvoobrazovanie (humus and pedogenesis). Leningrad.

Priori S, Pellegrini S, Perria R, Puccioni S, Storchi P, Valboa G, Costantini EAC (2019) Scale effect of terroir under three contrasting vintages in the Chianti Classico area (Tuscany, Italy). *Geoderma* 334: 99–112. https://doi.org/10.1016/j.geoderma.2018.07.048

Renwick A, Jansson T, Verburg PH, Revoredo-Giha C, Britz W, Gocht A, McCracken D (2013) Policy reform and agricultural land abandonment in the EU. *Land Use Policy* 30. 446–457. https://doi.org/10.1016/j.landusepol.2012.04.005

Serra P, Pons X, Saurí D (2008) Land-cover and land-use change in a Mediterranean landscape: A spatial analysis of driving forces integrating biophysical and human factors. *Applied Geography* 28: 189–209. http://doi.org/10.1016/j.apgeog.2008.02.001

Stanchi S, Godone D, Belmonte S, Freppaz M, Galliani C, Zanini,E (2013) Land suitability map for mountain viticulture: A case study in Aosta Valley (NW Italy). *Journal of Maps* 9: 367–372. https://doi.org/10.1080/17445647.2013.785986

Stefanovits P (1985) Soil conditions of the forest. Jakucs P (ed) *Ecology of an oak forest in Hungary. Results of „Síkfôkút Project" 1:* 50–57. Budapest

Štefunková D, Hanušin J (2019) Viticultural landscapes: Localised transformations over the past 150 years through an analysis of three case studies in Slovakia. *Moravian Geographical Reports* 27: 155–168. https://doi.org/10.2478/mgr-2019-0012

Stevenson I (1980) The diffusion of disaster: The phylloxera outbreak in the département of the Hérault, 1862–1880. *Journal of Historical Geography* 6: 47–63. https://doi.org/10.1016/0305-7488(80)90043-2

Sütő L (2013) A szénbányászat felszínfejlődésre és területhasználatra gyakorolt hatásai a Kelet-borsodi-szénmedencében (Effects of coal mining on geomorphological development and land use in the East Borsod Coal Basin). Nyíregyháza.

Sütő L, Balogh S, Novák TJ, Homoki E, Rózsa P (2021) A historic geographic approach to the anthropic disturbance in the Bükk region. *Acta Geographica Debrecina: Landscape and Environment Series*15: 58–65. https://doi.org/10.21120/LE/15/1/8

Sütő L, Dobány Z, Novák TJ, Adorján B, Incze J, Rózsa P (2017) Long-term changes of land use/land cover pattern in Human transformed microregions – case studies from Borsod-Abaúj-Zemplén County, North Hungary. *Carpathian Journal of Earth and Environmental Sciences* 12: 473–483.

Świtoniak M, Charzyński P, Novák TJ, Zalewska K, Bednarek R (2014) Forested hilly landscape of Bükkalja Foothill (Hungary). Świtoniak, M, Charzyński P (eds) (2014): *Soil sequences atlas:* 169–181. Torun.

Van Leeuwen C, Seguin G (2006) The concept of terroir in viticulture. *Journal of Wine Research* 17: 1–10. https://doi.org/10.1080/09571260600633135

Varga K, Dévai G, Tóthmérész B (2013) Land use history of a floodplain area during the last 200 years in the Upper-Tisza region (Hungary). *Regional Environmen-*

tal Change 13: 1109–1118. https://doi.org/10.1007/s10113-013-0424-8

Varga Z (2010) The post-socialist transformation of land-ownership relations in Hungary. Contexts of property in Europe. Congost R, Santos R (eds) *The social embeddedness of property rights in land in historical perspective:* 267–285. Turnhout. https://doi.org/10.1484/M.RURHE-EB.4.00074

Vaudour E (2002) The quality of grapes and wine in relation to geography: Notions of terroir at various scales. *Journal Wine Research* 13: 117–141. https://doi.org/10.1080/0957126022000017981

Vaudour E, Constantini EAC, Jones GV, Mocali S (2015) An overview of the recent approaches to terroir functional modelling, footprinting and zoning. *Soil* 1: 287–312. https://doi.org/10.5194/soil-1-287-2015

Vojtkó A (2001) A Bükk hegység növényföldrajzi felosztása. (Phytogeographical division of the Bükk Mountains). Vojtkó A (ed): *A Bükk hegység flórája:* 23–44. Eger.

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